ICEUBI2011
International Conference on Engineering UBI2011
Innovation & Development

MECHANICAL PROPERTIES OF NEEDLE-PUNCHED NONWOVENS FOR GEOTECHNICAL APPLICATIONS

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Conference Topic – CT 24 Textile

Abstract

The use of nonwoven fabrics in civil engineering applications has increased significantly in the last years due to the important characteristics and properties of such type of fibrous structure. The functions provided by nonwovens in geotechnical applications include drainage, filtration, separation, soil protection, particularly in its stability and erosion control.

In this study the influence of the aerial mass in the nonwovens mechanical properties including tensile, puncture and dynamic perforation (cone drop), have been studied.

The results obtained show that there is a significant correlation between the mechanical properties of the geotextiles and the aerial mass. Moreover, the use of a woven fabric as second layer in hybrid structures presents a positive effect to decrease the initial deformation under tensile.

Key Words: nonwoven, geotextile, mechanical properties.

Introduction

Textiles have increased significantly their specific and high performance applications. One of the main field of application for these materials is the construction industry. In this case, geotextiles play an important role in many applications such as road repair and construction. Geotextiles used in the construction sector are mainly produced by non-woven technology, representing approximately 70% of the whole amount of fabrics used for this purpose. (1)

The products used in geotechnical applications may present multiple functions, depending on their properties. The functions that this type of product can play includes: separation, reinforcement, filtration and drainage. Besides, the mechanical characteristics influence greatly the performance and functionality of the product. (2, 3, 5 and 7)

Geotextiles are fibrous structures with randomly oriented fibers, conventionally called nonwovens, presenting important properties and characteristics to be used in different kind of technical applications. As in the needled-punching nonwovens fibers are multidirectionally oriented, including in the third dimension, the tensile behaviour is highly dependent on the lateral pressure, as it controls the magnitude of the friction among fibers. Thus, when a nonwoven geotextile is subjected to a tensile load the fibrous network deforms to align the fibers in the direction of the force applied. (4, 5, 6 and 8)

The raw material is also a parameter influencing the geotextiles mechanical performance. (7) Different studies show that the nonwoven aerial mass and the density of needle penetrations in the production process can have significant effects on the nonwoven thickness.(7) Different studies on geotextiles for geotechnical application show that nonwoven fibrous structures have better performance than other fibrous structures. Nonwoven fabrics are more effective, in about 30%, than any other type of fabric for the the same aerial mass in terms of soil protection.(9)

Puncture resistance is one of the most important parameter in geotextiles, especially when used to perform the separation function. Tushar et al. studied the influence of radial pre-tension in woven and nonwoven samples. The work shown that lower failure strains in puncture if the samples are pre-stressed. This work also shown that biaxial failure strain is the most appropriate indicator of the failure strain in puncture than strains measured in uniaxial tests. (10)

This paper describes the work that is being undertaken at University of Minho in the development and optimization of needlepunched nonwovens for geotextile applications. The influence of the production parameters in the nonwoven mechanical properties have been studied, presented and discussed.

Materials and Methods

Materials

Different needlepunched nonwoven samples produced with a blend of polypropylene (PP), polyester and acrylic fibers with aerial mass of 106, 145, 208, 280 and 377 g/m^2, have been used to perform this studty. These samples are identified as A1, A2, A3, A4 and A5, respectively.
In addition, two hybrid fabrics have also been used to assess the combination effect of the different layers in the mechanical properties of the resulting nonwovens. The hybrid nonwovens are produced with a 100% PP nonwoven and with a 100% PP woven plain fabric. Table 1 shows the samples developed for the study.

Table 1: Samples developed and used for the study

Identification	Composition	Aerial Mass (g/m^2)
A1	PP/PES/PAC	106
A2	PP/PES/PAC	145
A3	PP/PES/PAC	208
A4	PP/PES/PAC	280
A5	PP/PES/PAC	377
A6 - hybrid	Nonwoven (PP/PES/PAC)+ Nonwoven (PP)	131
A7- hybrid	Nonwoven (PP/PES/PAC)+ Woven (PP)	346

Methods

To evaluate the mechanical properties of the samples produced different testing procedures have been applied.

Tensile strength

Tensile tests were performed according to Edana standard, Nonwovens tensile strength, 20.2-89. Tests were performed on a Universal Tensile Housfield H10KS. Five samples of 200x50 mm were tested in the transversal and longitudinal directions. The test was conducted at a crosshead speed of 100 mm/min, with a preload of 2 N.

Puncture strength

The puncture strength test was performed according to standard ASTM D6241 (2009) Test Method for Static Standad Puncture Strength of Geotextile and Geotextile-Related Products. In the tests the samples are placed between two circular plates and a load is applied out of the plan on the central part of the sample by a steel plunger. Ten samples with 150 ± 1 mm diameter were used and fixed in order to prevent slip occurence. Tests were performed on Universal Housfield H10KS dynamometer, at a 50 mm/min, with a preload of 0.1 N.

Dynamic perforation (Cone drop test)

The dynamic perforation test was performed according to standard EN 918:1995 Geotextiles and Geotextiles - Related Products Dynamic Perforation Test (Cone Drop Test). The test consists in the use of a cone penetration of steel with an angle of 45º and with a mass of 1000 grams. Ten samples have been tested and the results shows the behavior of geotextiles when hit by sharp objects.

Test results

Tensile tests

Figure 1 shows the results obtained in the tensile tests in the transversal direction.

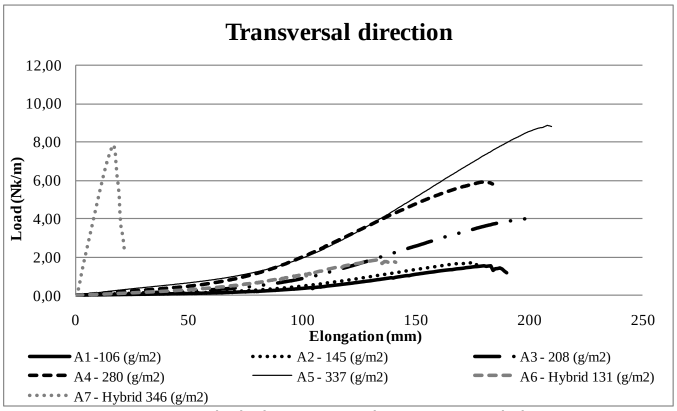

Figure 1: Tensile behaviour in the transversal direction

From Figure 1, it can be observed that the hybrid structure (nonwoven + woven) A7 with higher aerial mass shows less initial deformation which is related to a positive effect of the woven fabric used as second layer. In fact, the orientation of the fibers in the woven structute, placed at 0º and 90º, leads to a transference of the load applied directly to the fibers from the beginning of the test. As expected, the other hybrid structure (A6) shows a similar behaviour as the other structures (A1, A2, A3, A4 and A5), ie, there is large initial deformation for low loads until the break occurs. The structures having higher aerial mass present higher maximum tensile strength, due to the higher amount of fibers placed in the cross-section.
Figure 2 shows the tensile behaviour curves in the longitudinal direction.

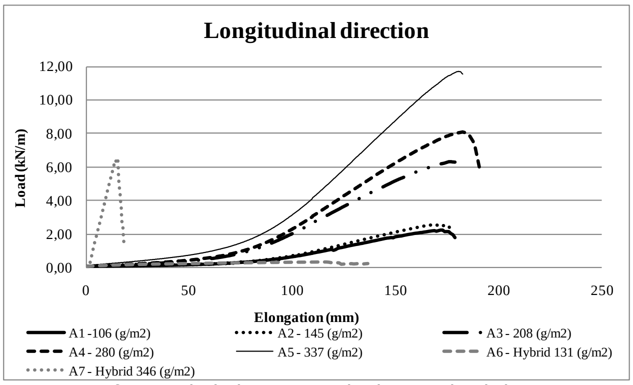

Figure 2: Tensile behaviour in the longitudinal direction

Analyzing the tensile behaviour in the longitudinal direction, it is verified that the increase in the aerial mass leads to an improvement in the mechanical performance for samples A1, A2, A3, A4 and A5. Sample A7, as for the transversal direction, is showing a lower initial deformation which demonstrates a positive effect of the woven fabric as second layer. However, hybrid sample A6, with a nonwoven as second layer, is showing similar behaviour when compared to the other types of non-wovens.

Puncture tests

Figure 3 shows the results obtained for the puncture test.

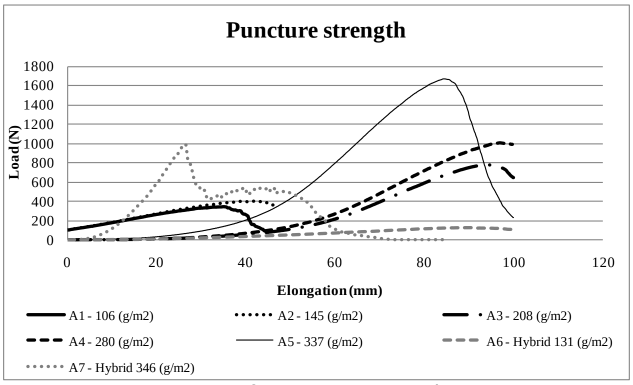

Figure 3: Puncture strength

According to the results obtained it is possible to verify that the hybrid structure with a woven in the second layer (A7) presents a structural deformation smaller than the other samples, showing a greater puncture strength. On the other side, the other hybrid sample A6, presents a similar behavior to the structures A3, A4 and A5, showing a similar initial deformation. Results show that an increase of puncture resistance is found when the aerial mass increases. The effect of a second nonwoven is not significantly affecting the puncture resistance.

Result analysis

Tensile strength

Figures 4 and 5 present the correlation between tensile strength, in transversal and longitudinal directions, respectively, and the aerial mass of the different nonwovens tested.

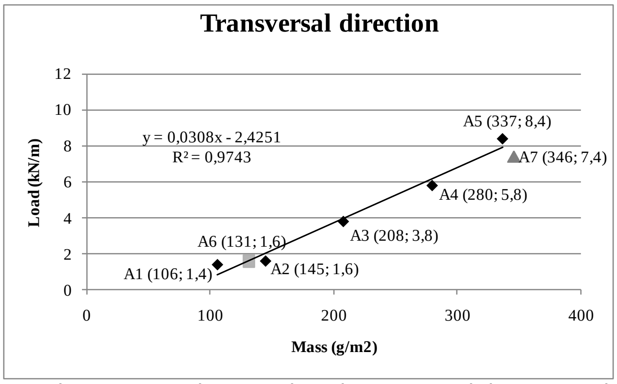

Figure 4: Correlation between Tensile strength in the transversal direction and the aerial mass

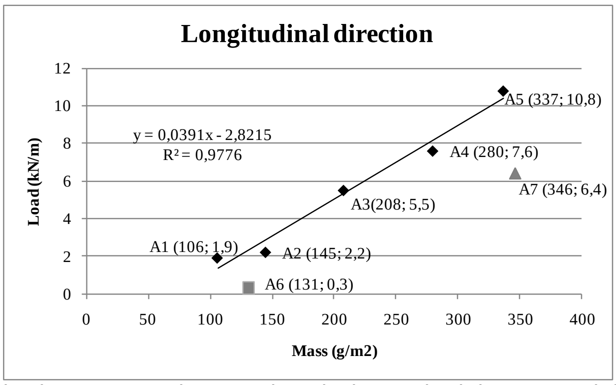

Figure 5: Relationship between Tensile strength in the longitudinal direction and the aerial mass

In both directions it is verified a very good linear correlation between these two paramenters, tensile strength and aerial mass. This means that the increase of the tensile strength is directly proportional to the increase of the aerial mass. Moreover, the results obtained for the hybrid samples show that the reinforcing structures used does not improve the tensile strength.

Puncture strength

Figure 6 shows the linear correlation obtained between puncture strength and the aerial mass for the nonwovens samples.

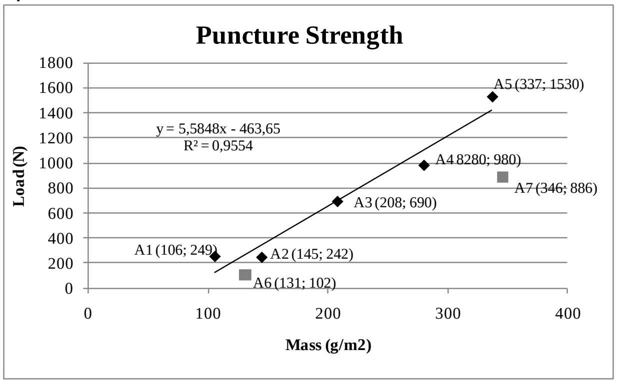

Figure 6: Relationship between static puncture strength and the aerial mass

As for the tensile testing, Figure 6 shows a very good linear correlation between the force required to break the samples and the aerial mass . However, it is also possible to observe that the hybrid samples do not follow this linearity, as the second layer is affecting the performance.

Dynamic Perforation (Cone drop test)

Figure 7 shows the correlation between the perforation diameter of the nonwoven and the aerial mass when suject to the cone drop test.

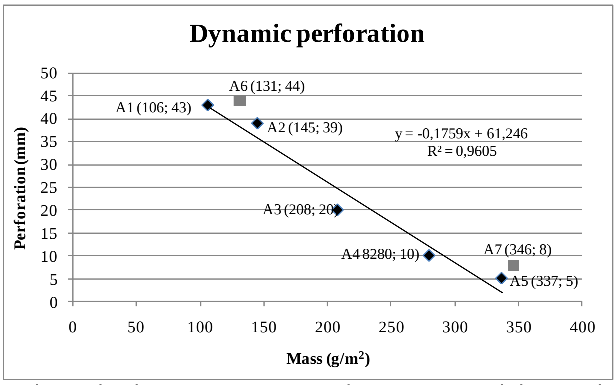

Figure 7: Relationship between Dynamic perforation test and the aerial mass

As can be seen, an inverse linear correlation betweem these two parameters is obtained. This means that when the aerial mass for the nonwoven sample increases the hole diameter formed by the steel cone decreases. This is due to the increase on the number of fibers in the cross section when aerial mass increases.

Conclusions

In this study the influence of the aerial mass in the nonwovens mechanical properties including tensile, puncture resistance and dynamic perforation (cone drop) have been studied. Siginicant linear correlations between aerial mass of the nonwovens and these mechanical properties have been found. Tensile strength and puncture resistance increase with the increase of the aerial mass of the nonwovens, while the perforation diameter decrease with the increase of the aerial mass. These results may be explained by the increase of the amount of fibers in the nonwoven cross-section as the aerial mass increases.

The results obtained also shows that the use of a second layer with fibers oriented at 0º and 90º, as in woven fabrics, may play a good effect on the mechanical response of the geotextiles as the fibers continuously oriented in these directions transfer imediatly the load applied to the structure avoiding the normal long initial deformation of this type of fibrous structure.

Results obtained within this study may represent an important tool to design the most appropriate nonwoven fibrous structure to a particular geotechnical application.

Acknowledgement

This work is being undertaken under the framework of the project nº 2010/11965, in partnership with the company PASTOFO, funded by QREN.

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